IoT-enabled Physical Telerehabilitation Platform

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***Abstract*—Physical telerehabilitation services over the Internet allow physiotherapists to engage in remote consultation with patients at their homes, improving the quality of care and reducing costs. Traditional visual approaches, such as webcams and videophones, are limited in terms of precision of assessment and support for assistance with exercises. In this paper, we present a Physical Telerehabilitation System (PTS) that enhances video interaction with IoT technology to monitor the position of the body of patients in space and provide smart data to physiotherapists and users. We give an overview of the architecture of the PTS and evaluate (i) its usability based on a number of interviews and focus groups with stakeholders, and (ii) its technical efficiency based on a series of measurements. From this evaluation, we derive a number of challenges for further improvement of the PTS and outline a possible solution based on a microservices architecture.**

I. Introduction

The evolving telecommunications industry combined with medical information technology has been proposing several solutions to provide remote medical services to people who live in rural areas and cannot travel to clinics due to disability or travel time/cost. Such solutions aim at improving the overall quality of healthcare, while reducing its cost.

In this context, *physical telerehabilitation* concerns the delivery of physical rehabilitation services over the Internet to people who cannot easily move from their home places to a clinic or consultation facility. Indeed, physical telerehabilitation allows physiotherapists to engage in remote consultation with patients dealing with e.g., stroke, surgical intervention recovery, and disabilities. For example, in the United States, stroke is a leading cause of disability and it accounts for 1.7% of national health expenditures. Since the population is ageing and the risk of stroke doubles after the age of 55 years, costs are expected to rise dramatically [1]. Hence, the use of telerehabilitation is promising to improve patients' access to recommended stroke treatments [2].

Physical telerehabilitation services can be categorized as physical assessment and physical therapy. Remote physical assessment concerns the evaluation of the body and its functions, whereas remote physical therapy concerns the assistance with specific prescribed exercises.

Most physical telerehabilitation applications are highly visual and the most commonly used modalities are webcams, videoconferencing, phone lines, videophones, and web pages containing rich Internet applications. However, current visual technology for physical telerehabilitation limits the quality and types of rehabilitation services that can be provided. In fact, the lack of spatial information inherent to 2D images (with no perspective cues) makes it difficult to provide both a precise evaluation of the body and its functions, as well as a full assistance with exercises. Using wearable motion sensors during remote physical rehabilitation sessions would open new opportunities to engage patients in progressive, personalized therapies with accurate feedback about the performance. Moreover, obtaining real-time data about the position changes of persons and their body parts (during clinical trials) would allow for (i) remotely verifying the integrity of complex physical interventions and compliance with practice, and (ii) capturing repeated outcome measures [3].

In this paper, we present a *Physical Telerehabilitation System* (PTS) that supports both the physiotherapist and the patients. The PTS enhances video interaction with IoT technology to monitor the position of the body in space and provide *data* to physiotherapists and patients.

The PTS can be considered a sociotechnical system [4]. Indeed, it is defined to explicitly include technical systems, operational processes, and people (including patients and the physiotherapist), which are considered inherent parts of the system. Due to its embeddedness in the society, the procurement and deployment of the PTS are influenced by the societal context, e.g., technology and regulations. Hence, it calls for employing modern architecture and infrastructure strategies able to accommodate continuous contextual changes. The trend is to switch thinking from composing components into one system to composing individual systems. To this end, we propose a microservice-based platform enabling the exploitation of IoT devices in the context of physical telerehabilitation. This will improve the sustainability of the system, by making it resilient to different types of uncertainty, ranging from societal to technical – e.g., regulations and communication technology.

We give an overview of the architecture of the PTS and evaluate both its technical efficiency based on a series of measurements and its usability based on a number of focus groups with stakeholders. From this evaluation, we derive a number of challenges for further improvement of the PTS and outline a possible solution.

The paper is organized as follows. Section II surveys related work. Section III describes the Physical Telerehabilitation System developed as part of the BoConnect project, whereas Section IV evaluates its usability and efficiency. Section V points out a set of key challenges that emerge from the evaluation, and Section VI describes a solution that aims at tackling them. Finally, Section VII concludes the paper and sketches our perspectives for future work.

II. Related Work

Research on telerehabilitation is manifold and ranges from technologies to assessment protocols and treatments. In order to deal with the heterogeneity of disabilities and meet the regulations, we need to develop telerehabilitation approaches, technologies, and protocols that are as effective and safe as traditional rehabilitation [5].

A traditional approach to telerehabilitation is remote monitoring and video-conferencing services [6], [7]. The primary goals of video-based telerehabilitation are: (i) simulation and training, (ii) video-consultation and remote diagnosis, and (iii) video-monitoring and vital signs tracking. However, although video monitoring has been shown to be successful in many different areas, there are many issues when applied to telerehabilitation. In particular, it is very difficult to obtain reliable and meaningful observations from the video only, while providing effective feedback to the patient remotely. Nevertheless, it might be possible to overcome these issues by applying various forms of telecommunication, including voice, video, and virtual reality [8].

Concerning the technologies, existing telerehabilitation systems for the treatment of physical pathologies make use of different types of interaction devices that can be classified in two main groups. The first group includes systems that exploit wearable motion sensors. Biotrack [9] is a serious-game system that makes use of markers and infrared cameras to evaluates whether people can reach some predefined locations. Whereas, in [10], the authors exploit smartphone's built-in sensors (e.g., gyroscope) to monitor exercise execution and provide feedback on exercise performance and execution errors. The second group includes those systems that employ non-intrusive tracking devices. In [11], the authors describe a telerehabilitation system that exploits the Nintendo Wii Remote to record user movements in 3D. In [12], the authors present an adaptive gaming system that tracks finger-hand movement: trackers, attached to objects, are captured by a webcam and used to evaluate the user's exercising quality, efficiency, and skills.

Concerning video-monitoring, most of the available systems rely on 2D video-streaming transmission, which in the case of physical telerehabilitation provides only a partial view of the patient's performance. This may hamper obtaining reliable observations (i.e., measurements) and thus provide effective feedback to the patient. On the other hand, 3D video-streaming can deliver additional information (e.g., depth) and assist the physiotherapists in evaluating the correctness of patient movements. However, transmitting 3D video requires high network bandwidth and efficient compression and transmission of 3D depth data is still an open problem [13]. A real-time video/depth/audio transmission is essential to achieve a convenient and effective telerehabilitation session and positive user experience. A physiotherapist should be able to demonstrate exercises remotely to the patient while also being able to observe patient's performance. Furthermore, the patients should be able to communicate to the physiotherapist any question or concerns about the exercises and their performance.

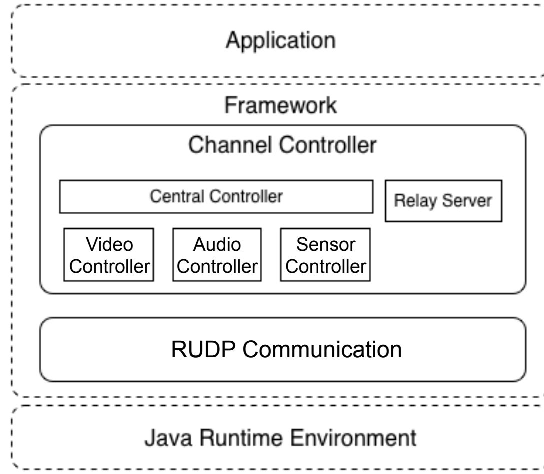


Figure 1: The Multichannel Communication Framework

Since avoiding delays in video-streaming and guaranteeing the stability of the communication are still challenging in 3D video transmission, our solution employs a multichannel communication approach that combines 2D video-streaming and high-performance data-streaming. The former is exploited for providing usual video-consultation, whereas the latter is leveraged for providing real-time streaming of monitored data (e.g., motion data).

III. BoConnect Project

BoConnect was a multi-disciplinary collaborative research project between Linnaeus University and Växjö municipality (Sweden, 2015–2016).[1] The project took a holistic perspective on assistive technologies and put user needs and reliability of the solutions in focus, both from a technological and organizational perspective. In this section, we focus on a Physical Telerehabilitation System (PTS), which was the subject of one of the sub-projects of BoConnect. In particular, we focus on the technical realization of PTS.

PTS employs a multichannel communication approach to transmit video-streaming along with data monitored by IoT devices – e.g., motion sensors. In the following Sections we

[1] https://people.cs.kuleuven.be/ danny.weyns/papers/2017BoConnect.pdf

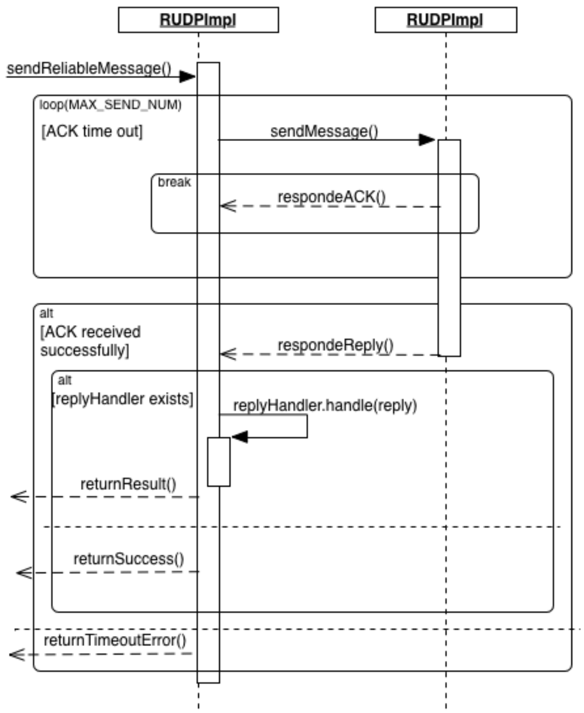


Figure 2: Reliable UDP

(i) discuss the design and implementation of a *Multichannel Communication Framework for IoT* (Subsection III-A), and (ii) present the *BoConnect Physical Telerehabilitation System* built on top of the framework (Subsection III-B).

A. Multichannel Communication Framework for IoT

Media synchronization represents a main challenge when developing real-time multimedia communication. Indeed, the random delay and loss of network packets make the synchronization between media very complicated.

The *Multichannel Communication Framework* aims at providing a set of generic functionalities for synchronizing multimedia data. In particular, the framework provides (i) a set of reliable message-oriented communication channels, and (ii) a channel controller responsible for synchronizing the different message flows.

As showed in Figure 1, the framework consists of two layers, namely *RUDP Communication* and *Channel Controller*. The *RUDP Communication* layer provides reliable message exchange communication between two nodes in the network. In particular, the layer implements the Reliable UDP protocol [14] and manages incoming/outgoing messages to/from *Channel Controller*. In contrast to reliable communication protocols (TCP in this context), UDP is unreliable and message delivery is not guaranteed (when a message gets lost, it is not sent again). Thus, in order to guarantee message delivery, the *RUDP Communication* layer enhances the UDP protocol with a delivery acknowledgment

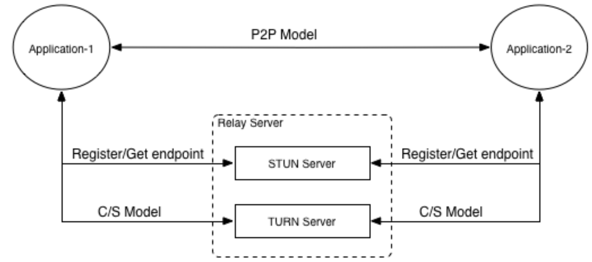


Figure 3: Interaction between Relay Server and applications

mechanism.

Referring to Figure 2, *RUDPImpl* implements the Reliable UDP protocol by defining two methods, namely *sendMessage* and *sendReliableMessage*. The method *sendMessage* is unreliable and is used for sending not critical messages. For instance, when performing video-streaming communication, both interacting parties transmit messages carrying image data. In this situation, losing some messages is acceptable, since it does not affect the video quality. Rather, retransmitting video messages would overflow the network and cause transmission delays. In contrast, the *sendReliableMessage* method is used to send reliable messages. Still referring to Figure 2, when *sendReliableMessage* is invoked and the message sent, *RUDPImpl* waits for an acknowledgement, i.e., `ACK`. If a timeout occurs, the system will try to send the message again until it reaches a *maximum* number of attempts. Once having received `ACK`, *RUDPImpl* either notifies the success, or waits for *reply* (if needed). In this case, it will use registered handlers to return the result to the proper calling component. If the message is lost, the failure is notified to the calling component.

The *Channel Controller* is responsible for synchronising the different communication channels, namely *video*, *audio*, and *sensor*. In particular, this layer contains two different types of controllers, *Central Controller* and *media channel* controllers. *Central Controller* is designed for managing registered *media controllers*. Whereas, *Video Controller*, *Audio Controller* and *Sensor Controller* manage the `VIDEO`, `AUDIO` and `SENSOR` message types, intended for transferring video data captured by a camera, audio data captured by a microphone, and generic data captured by a sensor, respectively.

As showed in Figure 2, the Multichannel Communication Framework includes also the *Relay Server* component. *Relay Server* is specifically designed for applying the *UDP hole punching* technique [15], which is needed to traverse NAT's [16] and establish peer-to-peer connections. Specifically, *Relay Server* contains two independent UDP servers, namely *STUN Server* and *TURN Server*.

The *STUN Server* acts as a rendezvous server for *UDP hole punching* and provides peers with a service discovery mechanism. It offers three main functionalities: (i)

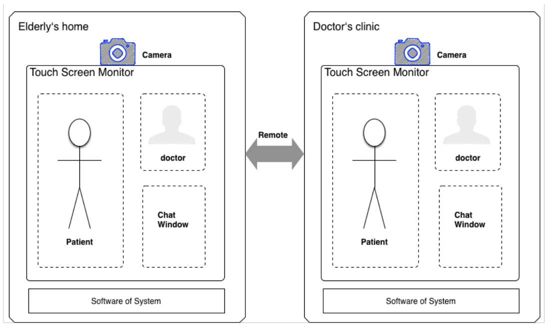


Figure 4: User Interface Mock-up

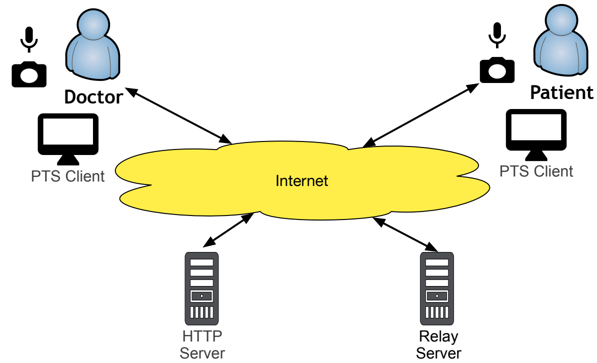


Figure 5: PTS Software Architecture

REGISTER private and public endpoints of peers, (ii) GETINFO about endpoints of a specific peer, and (iii) UNREGISTER the endpoints of the peer. The *TURN Server* is responsible for relaying messages among communicating peers. It offers two main services: (i) RELAY notifies the server to relay messages for the requesting peer, and (ii) UNRELAY notifies the server to stop the relay.

Figure 3 describes the communication model implemented by the Multichannel Communication Framework: *Application 1* and *Application 2* try to establish a direct peer-to-peer (P2P) communication trough the *STUN Server*; if the P2P communication fails due to NAT, then the framework automatically switches to Client/Server (C/S) and makes use of the *TURN Server* as intermediator to exchange messages.

B. Physical Telerehabilitation System

The *Physical Telerehabilitation System* (PTS) was designed in close collaboration with Växjö municipality (Sweden) that employs about 12 physiotherapists and 25 therapists responsible for a rehabilitation program involving more than 90 elderly. Since more than 50% of these elderly live in the countryside, developing a remote rehabilitation system would clearly improve the assistance service. The requirements were defined in consultation with the stakeholders. In particular, the PTS should provide:

- Video conferencing with support for text messaging;
- A tool to freeze a frame, enabling to better analyze the patient's posture;
- A drawing tool, to better explain actions and movements and enable patients to provide feedback;
- A basic level of security to log into the PTS;
- The PTS should respond efficiently with a regular Internet connection.

Figure 4 shows a mock-up of the intended user interfaces at the side of the elderly and the carer.

To realize the stakeholder requirements we designed the PTS software architecture shown in Figure 5. The PTS design relies on the *Multichannel Communication Framework for IoT*, and consists of three subsystems, *PTS Client*, *HTTP Server* and *Relay Server*. The *PTS Client* is executed both at the *Patient*'s and the *Doctor*'s side. The *HTTP Server* is responsible for managing registered patients and doctors, and providing secured sign in and sign out functionalities. Finally, the *Relay Server* is responsible for managing the communication between *Patient* and *Doctor*, either in Peer-to-Peer or Client/Server interaction mode. The different interaction modes (e.g., video conferencing, and text messaging) are realized by means of different channel controllers handling the underlying multichannel communication framework.

Figure 6 shows a screenshot of the client window of the PTS. The current version of the PTS provides patients and physiotherapists with a video conference service, as well as support for drawing, text messaging, and freeze-framing.

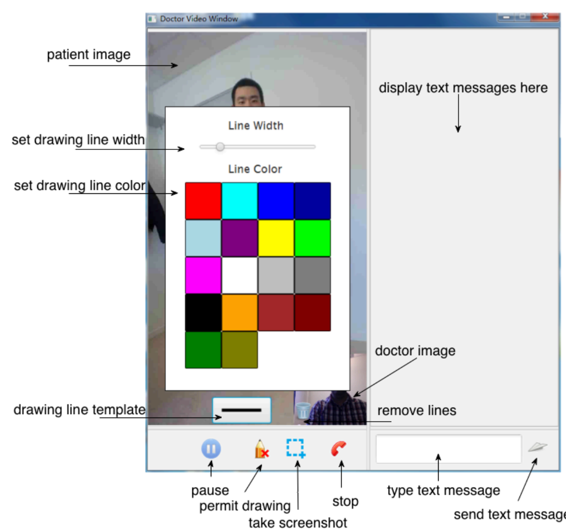


Figure 6: PTS Client - Main Window

IV. Evaluation and Evolution Needs

The evaluation of the PTS realization consisted of two parts: (i) evaluation of its usability based on a number of interviews and focus groups with stakeholders, and (ii)

evaluation of its technical efficiency based on a series of measurements.

A. Interviews and Focus Groups with Stakeholders

To fully understand the users, their context and needs the BoConnect project conducted a needs analysis based on a literature study, interviews with 15 elderly residents of the region (persons 65 years of age or older), and several focus groups with about 10 stakeholders from the care side. The aim of the study was to identify needs, both of the elderly and of other involved stakeholders, which could be addressed by assistive technology solutions.

The results of the different studies show that the factors for the successful design of assistive technology are participative design and a high level of individualization. Factors for successful use of technology are interoperability and the need for cross-institutional collaboration. Education is also a factor found to be of importance; all involved need proper education to utilize technology to gain meaningful use. Lack of knowledge and lack of sufficient infrastructure were factors the elderly individual themselves raised as hinders for successful use of digital tools.

Physiotherapists and stakeholders from management raised several issues with respect to the current realization. First, there is a need for high reliability of the service. An interruption of the service may bring elderly people in uncertain situations. Second, security is essential, not only in terms of access rights but also the protection of data that is transmitted between patients and doctors. Third, due to restrictions in terms of accuracy, the current version of the tool is applicable to a subset of elderly people; additional features such as sensors may enhance the applicability. Besides that, all the stakeholders acknowledge the high potential of the tool, which would increase the number of sessions with elderly substantially without incurring additional costs.

The studies made clear that telecare is expanding in the healthcare system, driven by the need to make the care more democratic and cost-effective. Stakeholders made clear that people with disabilities and/or far distance to healthcare facilities would benefit from receiving care in their homes. Then the public health and insurance stakeholders would save expenditures for travel besides the convenience for the individual. Many times the first assessment of an individual with e.g., a stroke is performed at a healthcare facility where a physical examination will take place. The follow-up and further rehabilitation will in most instances be possible at home in particular when the individual has sufficient cognitive function. Thus, when prescribing telecare, the physiotherapist or doctor must assess the cognitive function to select appropriate individuals – preferably at the healthcare facility but possibly also on distance. Stakeholders highlighted that family carers might be introduced to the remote system and assist the individual in the home. By employing sensor systems the need for physical follow-up will be compensated. For effective treatment and individual feedback a smoothly working telerehabilitation system is crucial. The general computer literacy of the population will pave the way for an increased use of Internet-based home care.

	Video	**Audio**	**Sensor**
Lost pck	12	4	0
Total pck	345	120	52
Loss rate	3.48%	3.33%	0.00%

Table I: Packet loss rate with C/S communication model

B. Technical Evaluation

Besides the needs analysis and stakeholder evaluation discussed above, we have also evaluated the PTS from a technical point of view. In particular, we evaluated the performance of the system by measuring *latency* and the *packet-loss rate*. The *latency* is measured as the time from the source sending a packet to the destination receiving it, whereas the *packet-loss rate* is measured as the fraction of the total transmitted messages that did not arrive at the receiver.

We evaluated both the P2P and C/S communications models by monitoring ongoing Patient-Doctor interactions, and analyzing the message flows within the different channels. For the sake of space, we report here only the results obtained for C/S communications models as they are more significative. In fact, having the *TURN Server* as intermediate between Patient and Doctor increases the channels latency.

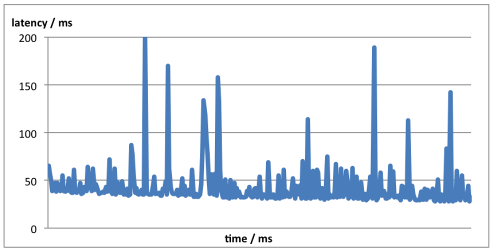
Figure 7 shows the average *latency* measured on *video*, *audio* and *sensor* channels, respectively. Note that we used the *sensor* channel to transfer chat and touchscreen messages. Since they are discrete, we plotted results by means of scatter graphs. In all graphs, the y-axis is the latency measured in milliseconds, and the x-axis is the duration of the Patient-Doctor interaction. Furthermore, Table I reports the packet loss rate measured for the three channels.

From above, we can see that the average packet loss rate for video and audio channels are 3.48% and 3.33% respectively, and the average latency is around $50ms$. These results are within the expected range and guarantee sufficient good quality of the remote service.

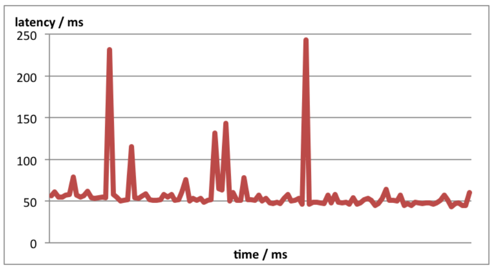
V. Challenges for Improvement

We highlight a number of key challenges to further improve the PTS that emerged from the evaluations.

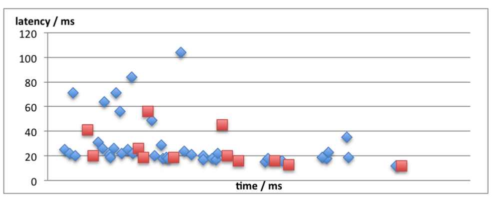
User management: There is an increasing list of potential users, including patients and doctors. The user management tool will require external connections for user management so that existing solutions can be integrated (such as Active Directory, Social Networks, etc.).



(a) Video Message Latency



(b) Audio Message Latency



(c) Data Message Latency

Figure 7: Message latency with C/S communication model

Personalization: The needs of the elderly people are highly personal and contextual. This requires that the PTS supports at least dedicated and smooth support for activation, de-activation, and configuration of its services.

Security and Privacy: Medical information is subject to strict security rules. For this reason, one of the requirements for a final solution to be used by medical institutions and elderly is that the communication between the peers needs to be protected by secure mechanisms. Currently, the PTS provides only basic mechanisms for access control. After the implementation of the user features, the possibility of communication via VPN tunnels can be studied. This may imply a CPU and bandwidth cost that should be studied under different setups.

Portability: The PTS uses Java libraries that require Windows infrastructure and Java 8 JRE. This limits the number of devices that can run the application. Support to port the application to other platforms is required.

Non-invasive sensing: A key concern at the heart of IoT that was clearly expressed by the patients is that they are not comfortable with wearing motion sensors. Patients reported that such sensors are not easy to use/apply and are perceived as invasive. To this end, the main objective for improvement of the PTS is to use non-invasive motion detection devices to improve the video-assisted remote physical rehabilitation services.

Bandwidth: The current implementation demands a high bandwidth (820KBps). We expect to improve this with a new implementation of the video streaming. Currently, we are focusing on using frame rates of 25Hz and 50Hz with 320x240 px per image. We initially aim at 600KBps upload and 600KBps download (Skype-alike). The application of wired, wireless, and 4G/3G connections are subject to study.

In the next section, we outline an evolution of the architecture that aims to tackle these challenge.

VI. Physical Telerehabilitation Platform

An important overall insight that emerged from the evaluation of the PTS is the need for a *sustainable solution*. That is, the system should be resilient to a variety of uncertainties, ranging from societal to technical, such as evolutions of needs, situations, regulations, personal, and technology.

To this end, we need to switch thinking from composing components into one "monolithic" system to composing individually scaling systems that are available into an integration platform. Such platforms should be expandable and provide developers with proper mechanisms to develop new services and mitigate the different types of uncertainty [17]. Furthermore, the platform should be *designed for sustainability* and have adaptation and evolution as driving design principles to accommodate ever-changing social and technical needs [18].

Due to adaptivity and evolvability, IoT-based applications are characterized by a highly dynamic software architecture where both the architectural entities (including services and things) and their interconnections may change over time. To accommodate the required level of adaptivity and evolvability at the application level, a generic IoT platform should be able to accommodate continuous structural change without adversely affecting the application's behavior. Hence, the IoT platform is required to be "fluid" and able to accommodate continuous architectural changes [19]. In order to achieve architectural fluidity, enabling properties are: (i) *loose coupling*, an IoT entity is deployed and executed independently of other entities, (ii) *flexibility*, IoT entities can be added/removed into/from the running application, (iii) *dynamism*, IoT entities of interests are discovered and bound into the running application, and (iv) *serendipity*, unforeseen IoT entities are accommodated into the running application. Hereafter, we discuss a set of key design principles that allow the IoT platform to be fluid and adapt/evolve depending on the changing situations/needs.

Isolation is considered one of the most important design principles, as its systematic application allows architects to slice up the architecture and organize its responsibilities accordingly. A responsibility is defined as "a reason for change" [20], which in turn is driven by a need. When a new uncertainty emerges, it will affect the system and may require to a change of responsibilities of services within the platform. Hence, the more responsibilities a service assumes, the more uncertainties will affect it. In the long-term, this will lead to a fragile design and platform architecture erosion.

To this end, the *Single Responsibility Principle* (SRP) plays a key role in designing architectures that are resilient to uncertainties. Specifically, SRP states "Gather together those things that change for the same reason, and separate those things that change for different reasons" [20]. That is, the architecture should consist of a set of autonomous and isolated services that have only one responsibility (i.e., only one reason to change) each. Then, a single uncertainty can affect a single service, without compromising the entire architecture. In practice, each distinct service should have isolated persistence, a distinct domain model, user interface, implementation strategy, and (a) development team(s). Isolation natural supports the adoption of continuous delivery [21], which in turn allows for rolling out changes incrementally, service by service.

Once having a set of autonomous and isolated services, they must be composed together and collaborate with one other to provide the required user functionality and quality. It is in the collaboration that opportunities and challenges emerge. Service composition puts the system at high risk since the overall behavior can not be guaranteed in case of interaction deviate from the expectation, e.g., due to failures, system overloading, etc. To that end, it is important to take precautions and be robust with respect to communication [22]. Adhering to the *Robustness* principle "be conservative in what you do, be liberal in what you accept from others" improves interoperability among services and facilitates their evolution.

The Microservices Architecture [23] style decomposes a system into discrete and isolated single-responsibility services that communicate with well-defined protocols. Specifically, the Microservices Architecture advocates creating a system from a collection of small services, each with its own data, that interact via message-passing. Isolation and Single Responsibility allow for implementing systems adhering to the *shared-nothing design principle*, where services are independent and do not share any resource, e.g., memory or disk storage. This removes any single point of failure, and provides for *elasticity*, *responsiveness*, *resiliency*, and *scalability*, as services can be easily added/removed/replaced at runtime, whenever needed.

Referring to Figure 8, the *IoT-enabled Physical Telerehabilitation Platform* adheres to the microservice architecture paradigm and implements a set of independent single-responsibility services, each providing a specific functionality. *Auth* plays a central role, as Security and Privacy are key requirements. All the other services in the platform have

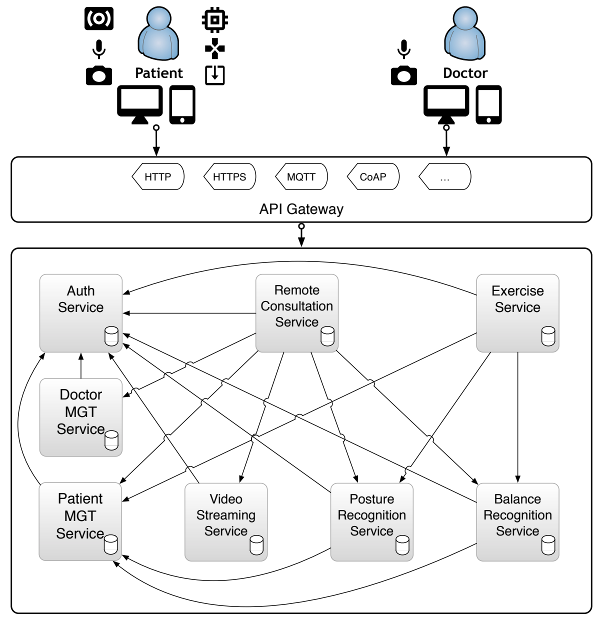


Figure 8: IoT-enabled Platform – Microservice architecture

Auth as dependency, and must check the client's identity before serving it. *Remote Consultant* provides the remote telerehabilitation functionality by allowing a doctor and a patient to interact with one another. To this end, *Remote Consultant* composes different functionalities, namely *Video Streaming*, *Posture Recognition*, and *Balance Recognition*. Note that *Remote Consultant* also depends on *Doctor Management* and *Patient Management*, which store personal information about doctors and patients, respectively. On the other hand, *Exercise* provides offline telerehabilitation functionality, allowing the user to perform a set of exercises that are automatically evaluated by the system. Therefore, *Exercise* exploits *Posture Recognition*, and *Balance Recognition* services.

Due to the fine-grained nature of the microservices API, each invocation would return only a portion of required functionality of the PTS. This would require client applications (either *Patient* or *Doctor*) to make multiple invocations in order to render a single user experience. In order to solve this issue, the platform implements an *API Gateway*, which serves as entry point for the clients. Using the API gateway: (i) hides the internal partitioning of the platform into microservices for clients, (ii) hides the locations of microservice instances to clients, and (iii) provides clients with personalized APIs through different communication protocols (e.g., HTTP, MQTT, and CoAP). When accessing the *API Gateway*, clients are provided with a different API depending on their specific role, namely *Patient* and *Doctor*. For example, still referring to Figure 8, *Patient* will be provided with an API capable of handling many different IoT devices (e.g., motion sensor and balance board), whereas

Doctor is provided with an API capable of handling camera and microphone only. Whenever new services and devices are added to the platform, the API Gateway is automatically updated and the new API will be made seamlessly available to the clients.

VII. Conclusion and future work

In this paper, we presented a physical telerehabilitation system based on IoT technology. We discussed the technical realization of the PTS that was developed in the context of the BoConnect research project in Växjö Sweden. We evaluated both the usability of the PTS and its performance, the former based on a series of interviews and focus groups with stakeholders in the field. From the evaluation, we synthesized a number of key challenges that need to be tackled to make the PTS ready for use in practice at large scale. Key challenges include personalization, security and privacy, non-invasive sensing, performance, and portability. To tackle these challenges, we outlined an IoT-enabled Physical Telerehabilitation Platform adhering to the Microservices A rchitecture style. However, besides the technical challenges, the most important challenge in this domain is to deal with its inherent multi-disciplinary character of the problem domain and the need for close interaction with stakeholders in the field. From the BoConnect project, we learned that the importance of a multi-disciplinary approach that puts stakeholders in the center of the engineering activities has never been so important as for IoT applications.

Acknowledgment

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